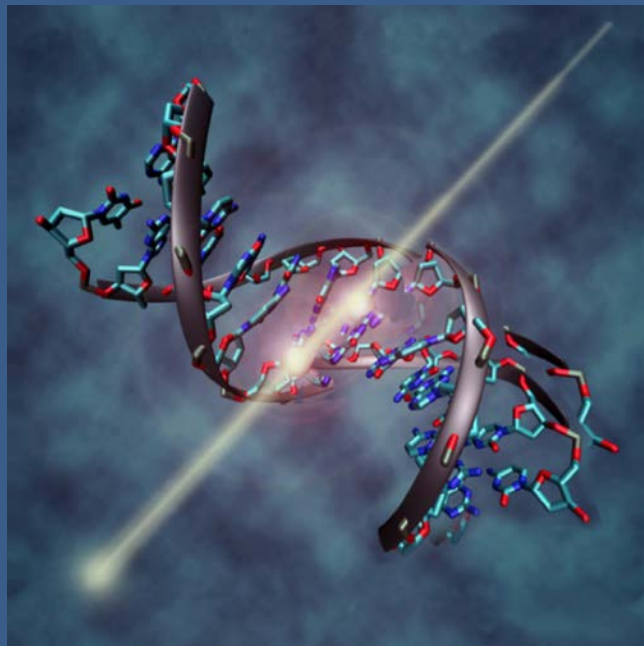


BioSentinel Mission: “Canary in a Coal Mine”

•Quantify DNA damage from space radiation environment

- Space environment cannot be reproduced on Earth: omnidirectional, continuous, low flux, variety of particle types
- Health risk for humans spending long durations beyond LEO
- Radiation flux can spike 1000x during a solar particle event (SPE)

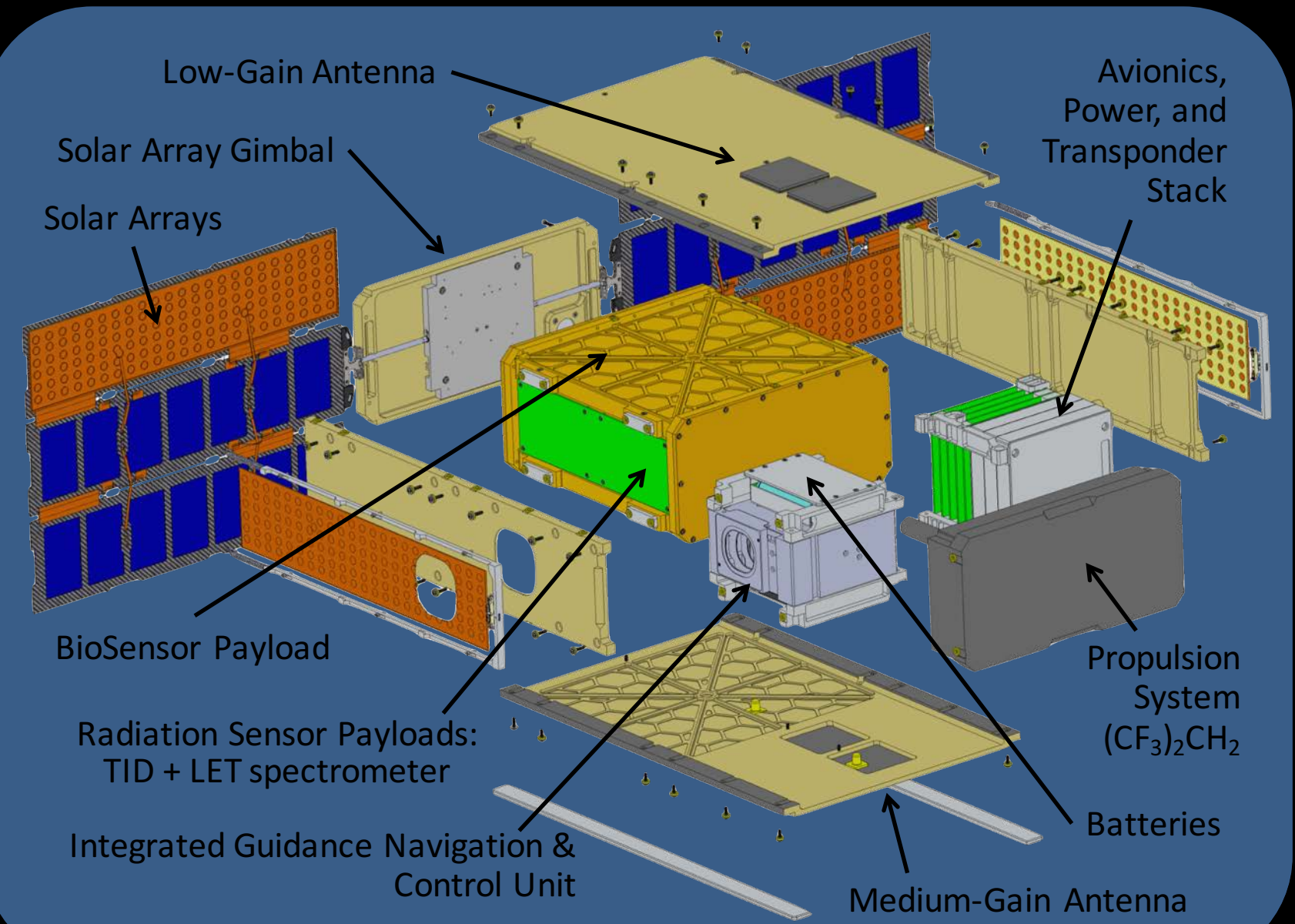


•Yeast assay: microfluidic arrays monitor DSB/repair

- Three strains of *S. cerevisiae*: 2 controls, 1 engineered strain
  - Engineered strain quantifies double strand breaks (DSBs)
- Wet and activate multiple banks of microwells over mission lifetime
- Double strand break & associated repair enable cell growth & division
- Reserve wells activated autonomously in case of SPE

•Correlate biological response with physical radiation measurements

- **Total Ionizing Dose** (TID) sensor measures integrated deposited energy
- **Linear Energy Transfer** (LET) spectrometer bins and counts particle events



6 U volume

14 kg mass

30 watts power

3 science payloads

1.3 krad-Si after 1 year

Cold gas reaction control

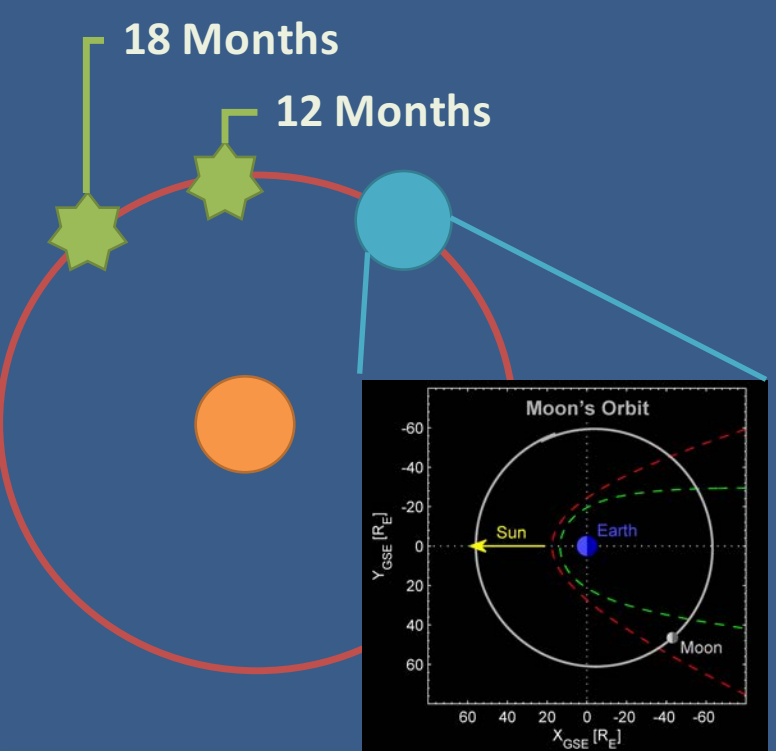
3 degree of freedom attitude control

Spacecraft Design: 6U Cubesat

- A “6U” (10 x 22 x 34 cm) nanosatellite
- First NASA biological study beyond low Earth orbit (LEO) in over forty years
- Results will be compared to data obtained in LEO (on International Space Station) and on Earth
- Active attitude control required for RF communication and solar power generation

Concept of Operations: Deep Space

- Secondary payload aboard Space Launch System (SLS) Exploration Mission (EM) 1
- Launch from Kennedy Space Center (KSC)
- 12- to 18-month mission lifetime
- Earth-leading ~0.93 – 0.98 AU heliocentric orbit
- The 95% maximum dose probability with 1.85 mm of aluminum over 1 year is about 1.3 krad-Si.



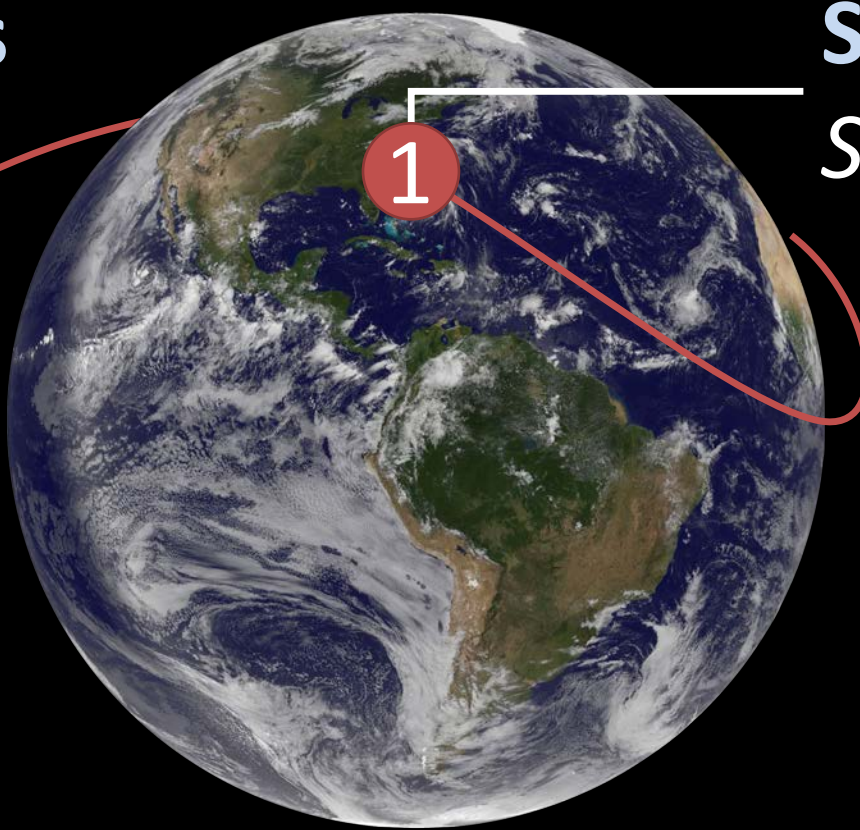
BioSentinel

Mission Development of a Radiation Biosensor to Gauge DNA Damage and Repair Beyond Low Earth Orbit on a 6U Nanosatellite

Hugo Sanchez, Brian Lewis, Robert Hanel,  
NASA Ames Research Center, Moffett Field, CA, USA

5 hours, 17k miles  
System Initiation

Summer 2018, KSC  
SLS EM-1 Launch



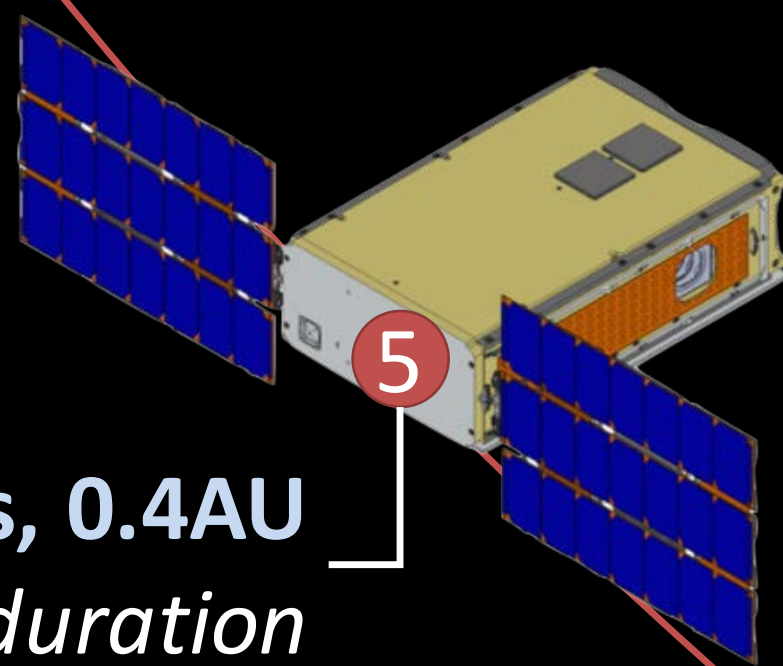
5 Days, 240k miles  
Lunar Flyby



9 months

Equal to round trip  
asteroid mission

4



12 months, 0.4AU  
Nominal mission duration

18 months, 0.75AU

Max mission duration

Equal to round trip Mars mission

6

**BioSentinel Team – NASA ARC:** Sharmila Bhattacharya, Antonio J. Ricco, Elwood Agasid, Debra Reiss-Bubbenheim, Tore Straume, Macarena Parra, Travis Boone, Sergio Santa Maria, Ming Tan, Diana Marina, Aaron Schooley, Shang Wu, Matthew Sorgenfrei, Matthew Nehrenz, Abe Rademacher, Terry Lusby, Vanessa Kuroda, Craig Pires, Josh Benton, Doug Forman, Ben Klamm, Andres Martinez, Brittany Wickizer. **NASA Johnson Space Center:** Bobbie Gail Swan, Edward Semones, Scott Wheeler, C. Mark Ott, and Sarah Castro

Fault Modes Definition: FMECA

- Performed spacecraft level Failure Modes, Effects, and Criticality Analysis (FMECA)
  - Example of tables/process below
  - Example case is for a reaction wheel failure (RW pictured on right)
- FMECA identified items that would be addressed with flight software, MOS procedures, design updates, and minimum risk design approaches



Failure Mode Number	Item or Function	Failure Source a. Failure Mode b. Failure cause	Failure Effects a. Local b. System c. Mission	Consequence Level	Remarks a. Detection Method b. Compensating Features c. Other	Fault Mode Responses
Example 1	Comm with Ground	a. No ground commands b. RW speed saturation	a. RW limited b. Increasing rates c. No new commands	4	a. IMU rate data b. Vendor testing c. Rate reduction tested during checkout	High speed activates propulsion
Example 2	Comm with Ground	a. No ground commands b. ADCS overload	a. No RW response b. Increasing rates c. No comm	5	a. Current sensors b. Vendor testing c. Rate reduction tested during checkout	High current limit turns off wheels

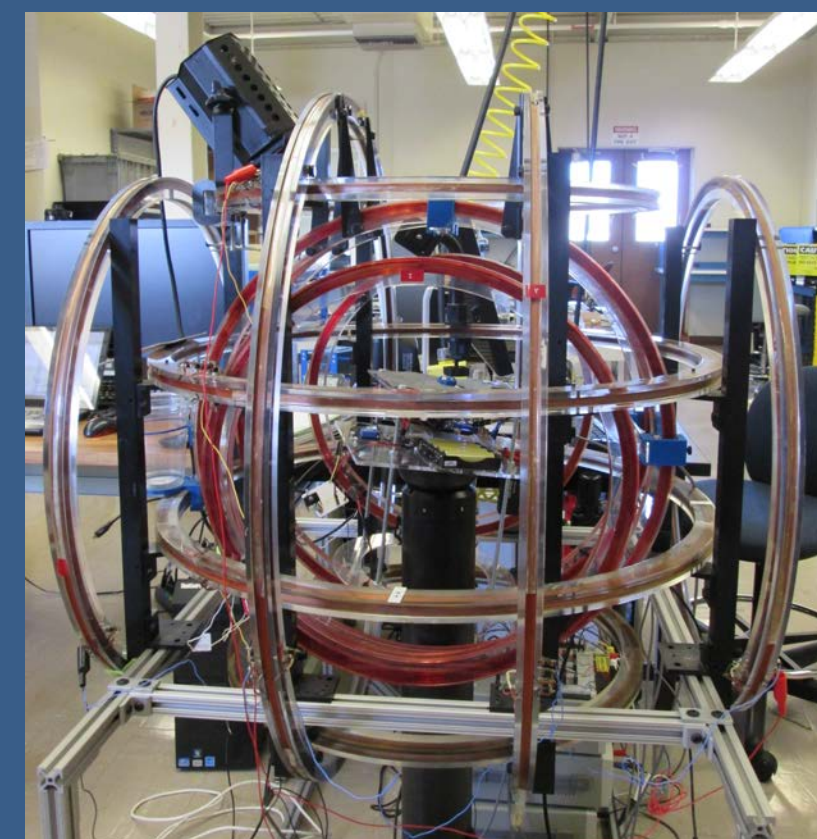
Fault Mitigation: Detection and Response

- Fault Management Plan addresses items assigned to flight software
  - Source (mnemonic) of on-board telemetry required
    - Watch Points developed with name, mapping to software modules, and thresholds in engineering units
    - Added to ICDs if not already available
    - Includes thresholds and persistence
- Added items based on review of LADEE fault management plan
- Added items based on review with payloads, MOS, spacecraft teams
- Core Flight Services (cFS) Limit Checker Module used for implementation

Watch Point #	Description	Software Module	Comparison Value
8	Reaction Wheel 1 current sensor	EPSIO	>500 mA
41	Reaction Wheel 1 Soft Speed Limit	BCTIO	>2000 rpm
44	Reaction Wheel 1 Hard Speed Limit	BCTIO	>4500 rpm

Verification: Testbeds

- Electrical Power System (EPS) Engineering Development Unit (EDU) hardware
  - Used to replicate over current and verify response
- Generalized Nanosatellite Avionics Testbed (G-NAT)
  - Testing data and general test protocols for sensors, actuators, and processors
  - An air bearing allows for three degrees-of-freedom (3-DOF) rotational motion within a Helmholtz cage
  - “Attitude truth” resolved from a set of infrared LEDs being tracked using a COTS digital camera.



Summary

- BioSentinel is deep space cubesat mission that will require autonomous 3-DOF attitude control in a high radiation environment
- 35 failure modes identified in FMECA with 35 possible implementations of mitigations in flight software
- Action Points table developed with Boolean logic for watch point combinations